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OPTICAL FINGERPRINT IDENTIFICATION BY BINARY JOINT TRANSFORM CORRELATION

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13. ABSTRACT (Maximum 200 words)

We describe an optical fingerprint identification system that optically reads a latent fingerprint for correlation using a binary joint transform correlator. The fingerprint is read using the total internal reflection property of a prism. The system was built, using a guide to keep the finger in the same orientation each time. There were no false alarms.

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1. INTRODUCTION

The purpose of research efforts in optical signal processing is to develop techniques leading to systems that optically process data at very high rates of speed, preferably with smaller volume and lower power requirements. Image processing systems based on the joint Fourier transform technique[1] (JTC) have been shown to have good performance.[2,3,4,5] Binarizing the joint power spectrum (JPS) of the JTC provides significantly higher peak intensity, larger

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[1] Weaver, C.S. and Goodman, J.W. (1966) A technique for optically convolving two functions, *Appl. Opt.* **5**:1248.

[2] Yu, F.T.S., Jutamulia, S., Lin, T.W., and Gregory, D.A. (1984) Adaptive real-time pattern recognition using a liquid crystal TV based joint transform correlator, *Appl. Opt.* **26**:1370.

[3] Florence, J. (1989) Joint-transform correlator systems using deformable-mirror spatial light modulators, *Opt. Lett.* **14**:341.

[4] Javidi, B. and Horner, J.L. (1989) Multifunction nonlinear signal processor: deconvolution and correlation, *Opt. Eng.* **28**:837.

[5] Tam, E.D., Yu, F.T.S., Gregory, D.A., and Juday, R.D. (1990) Autonomous real-time object tracking with an adaptive joint transform correlator, *Opt. Eng.* **29**:314.

peak-to-secondary ratios, delta-like correlations, and better cross-correlation discrimination.[6] We present a system using a prism operating in the total internal reflection mode to optically generate a high contrast image of a fingerprint[7,8] that is used as an input to the binary JTC (BJTC) for comparison with a data base. This compact system operates in near real-time, and has good discrimination capability. While this system is ideally suited for secure entry systems to identify individuals for access to a restricted area, it could be used for mobile and remote surveillance by law enforcement agencies.

2. THEORY

2.1 Prism - Total Internal Reflection

High contrast images of a fingerprint can be read optically using a standard 90 degree prism where the read beam is directed at the critical angle.[7,8] When the laser beam enters one side of a 90 degree prism and strikes the hypotenuse at an angle given by

$$\theta_c = \arcsin\left(\frac{\eta_t}{\eta_i}\right). \tag{1}$$

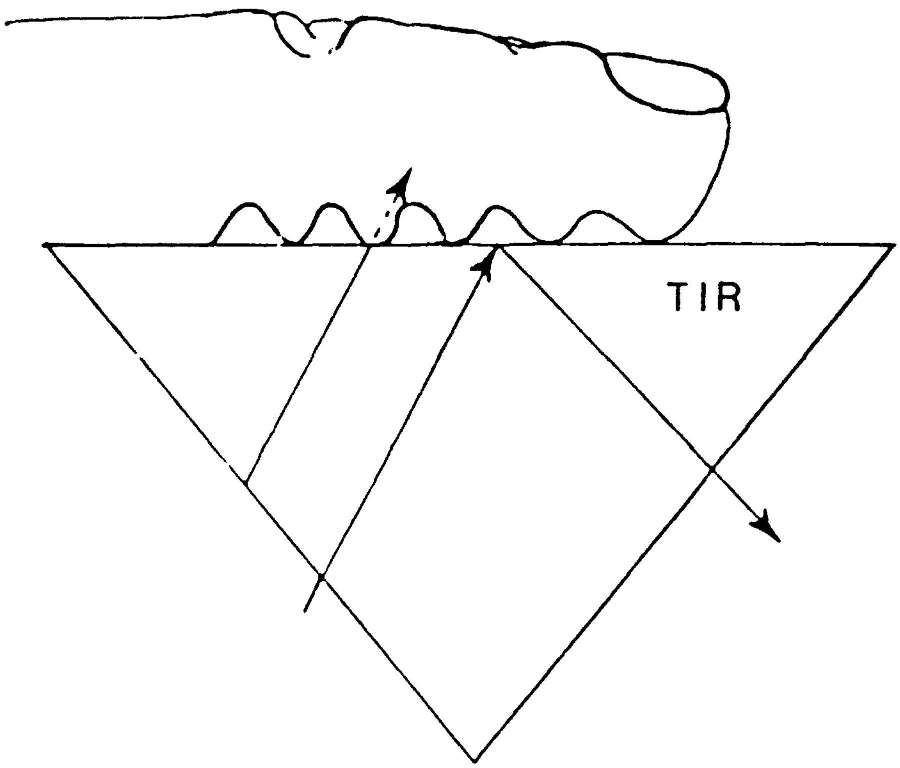
the transmitted light will travel tangentially to the glass medium interface. Incident angles beyond θ_c will cause the light to be totally internally reflected in the prism and pass out the opposing side. This assumes ($\eta_i > \eta_t$) where η_i and η_t are the indices of refraction of the prism glass and external medium.

Placing a finger on the hypotenuse side of the prism, shown in Figure 1a, changes the boundary conditions; so that where ridges of the fingerprint make contact with the glass, the natural oils of the skin make a good optical bond and the light wave is transmitted and largely attenuated by the skin. Where the ridges don't make contact the light is totally internally reflected by the interface and captured by the input camera. An example of the captured print is shown in Figure 1b. Figure 1c shows the print binarized around its mean value. This print is sent to the BJTC for comparison with a database of fingerprints to determine the individual's identity.

[6] Javidi, B. and Kuo, C. (1988) Joint transform image correlation using a binary spatial light modulator at the Fourier plane, *Appl. Opt.* **27**:663.

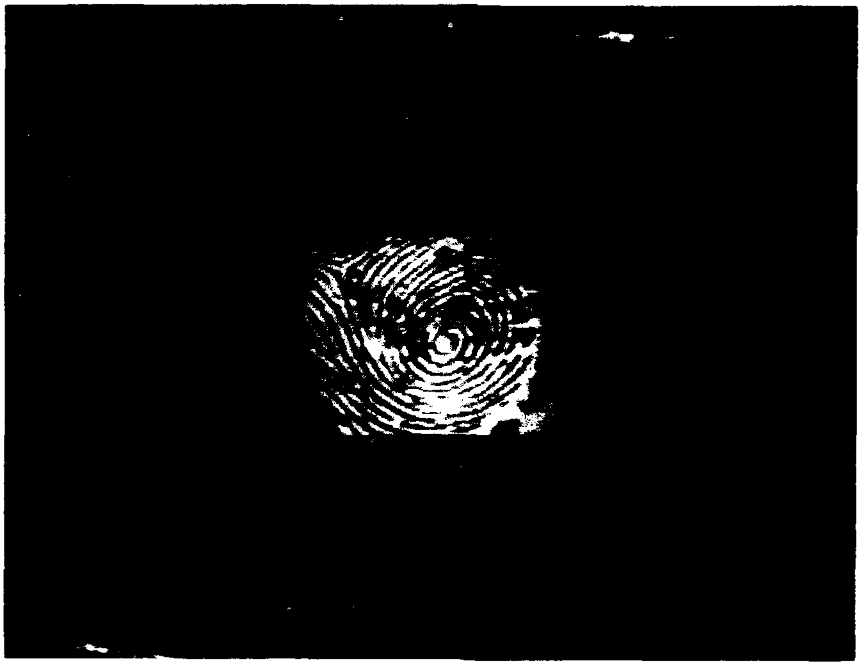
[7] Shimizu, A. and Hase, M. (1984) Entry method of fingerprint image using prism, *Trans. Inst. Electron. and Commun. Engineers of Japan Part D*, **J67D**(no 5):627.

[8] Gerhardt, L.A., Attili, J.B., Crockett, D.H., and Presler, A.M. (1986) Fingerprint imagery using frustrated total internal reflection, *Proceedings of the 1986 International Carnahan Conference on Security Technology*, 251.



1a

Figure 1. a) An Exaggerated View of the Finger in Contact with the Prism, b) a Typical Fingerprint Image, c) the Fingerprint Binarized Around its Mean Value.



1b

1c

2.2 Binary Joint Transform Correlator

For the JTC architecture shown in Figure 2, the reference and target image are placed on their respective halves of the input spatial light modulator (SLM) and are denoted by $r(x + x_0, y)$ and $s(x - x_0, y)$. The Fourier transform of this input, called the joint power spectrum (JPS), is captured by a square law detector and Fourier transformed. It can be shown that the resulting correlation signals are given by

$$h(x_1, y_1) = R_{R,R}(x_1, y_1) + R_{S,S}(x_1, y_1) + R_{R,S}(x_1 - 2x_0, y_1) + R_{S,R}(x_1 + 2x_0, y_1) \qquad (2)$$

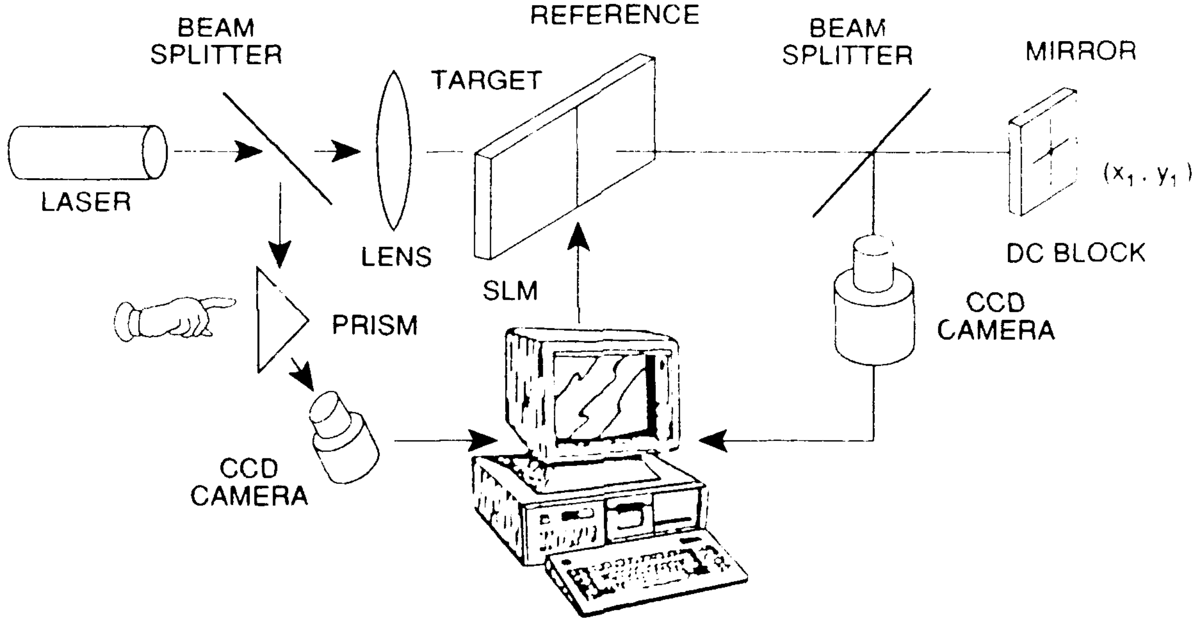


Figure 2. Compact 1-f Correlator Configuration.

The first two terms are on-axis autocorrelation terms, the correlation of reference and target signals with themselves, and the third and fourth terms are the correlations of the reference with the target.

Javidi was the first to binarize the joint power spectrum[6] (JPS) and formalized the kth law nonlinearity revealing an interesting family of correlation types varying in sensitivity.[9] Although our work is performed using a binary SLM, the full potential of the fingerprint

[9] Javidi, B. (1989) Nonlinear joint power spectrum based optical correlation. *Appl. Opt.* **28**:2358.

correlator should be realized using a grayscale device. By applying a nonlinear operation on JPS and following the theoretical development of Reference 9, we find the output field of the nonlinear system is made up of harmonics with the first term containing the correct phase information and largest intensity. The general equation for this first harmonic is given by[9]

$$g_{1k}(E) = \frac{2\Gamma(k+1)\left(R(\alpha,\beta)S(\alpha,\beta)\right)^k}{\Gamma\left(1-\frac{1-k}{2}\right)\Gamma\left(1+\frac{1+k}{2}\right)} \cos\left(2x_0\alpha + \phi_s(\alpha,\beta) - \phi_R(\alpha,\beta)\right) . \tag{3}$$

To better understand the nonlinear process, let us vary k and compare the field in Eq. (3) to the field exiting the filter of a frequency plane correlator.[9,10] Assuming the target and reference are identical and letting $k = 1$, Eq. (3) reduces to the field one expects to leave the Fourier plane of a frequency plane correlator employing a classical matched filter. If $k = 0.5$, the field is similar to a phase-only filter based correlator; and if $k = 0$, the hardclip binarization we use here, the analogy is to the inverse filter correlator since all amplitude information of both the input and reference signals have been eliminated. These filters are successively more sensitive to input object distortions, so by varying the nonlinearity, k, the sensitivity of the system to target image distorations can be changed. We feel this concept of varying the sensitivity is extremely important in this system. It is probably not ideal to compare images at either extreme of the scale presented here. If $k = 1$, the system is likely to be fairly insensitive and false alarms will occur, while if $k = 0$ the system will be too sensitive, requiring the target print to be extremely similar to the reference for correct identification. In the next section we describe our experimental results comparing fingerprints from several individuals. We have successfully identified individuals using a system employing a binary SLM, encouraging us to pursue this research with a grayscale device.

3. *EXPERIMENTAL METHOD AND RESULTS*

The compact optical BJTC system is shown in Figure 2. A 10mW He-Ne laser is the source and the SLM used is the SEMETEX 128x128 binary electrically addressed device. A DC block is used in the Fourier plane to more accurately capture the JPS.[10] We have previously shown that the correlation peak intensity can increase by a factor of 2 using the DC block. The fingerprints of 5 individuals were compared to evaluate the effectiveness of this system. Two distinct fingerprints from the right-hand index finger of each individual are obtained and stored in the computer in 128x128 data files. Each fingerprint is compared with all other

[10] Fielding, K.H. and Horner, J.L. (1990) *1/f Binary Joint Transform Correlator*, RADC-TR-90-201.

fingerprints in the data base. The two fingerprint images to be compared are separately binarized around their respective average value and reduced to 64x64 images that are placed together on the SLM. The JPS is captured by a CCD camera and binarized around its average value. The binarized JPS is displayed on the SLM, and the resulting correlation observed. Table 1 shows the results. A + sign indicates a proper identification, while a – sign indicates a correct "no match" response. The indication was simply the presence or lack of a clear and distinct correlation peak. In our limited trials we had no false alarms. We should mention that a guide was fashioned on the prism to help the individuals place their finger in the same orientation for each measurement. This is essential when dealing with the sensitive BJTC.

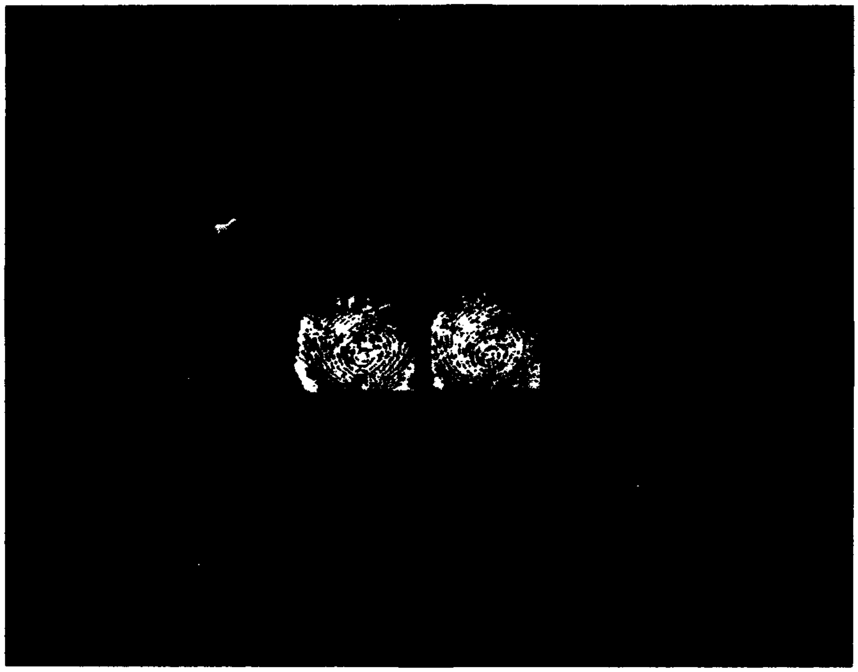
Table 1. Results of the Fingerprint Comparison Trails

Fingerprint	F1A	F2A	F3A	F4A	F5A
F1B	+	–	–	–	–
F2B	–	+	–	–	–
F3B	–	–	+	–	–
F4B	–	–	–	+	–
F5B	–	–	–	–	+

Figure 3a shows the binarized fingerprints of an individual placed on the SLM. The print on the left is the stored reference while the fingerprint on the right is optically read and fed into the system. The binarized JPS of this input is shown in Figure 3b with the corresponding correlation shown in Figure 3c. The correlations nearest the DC block are from the zeroth order while the outside correlations are from the first replicated orders. The peak-to-secondary ratio of the correlation is 3-to-1 while the signal-to-noise ratio (SNR) is 27 using the metric[10]

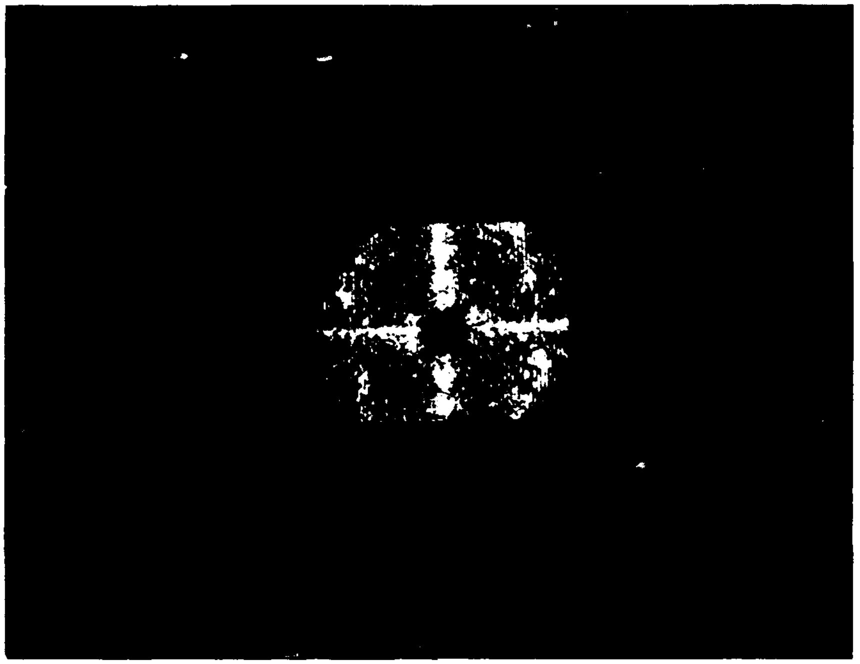
$$SNR = \frac{C_0}{N_{RMS}} \tag{4}$$

where C_0 and N_{RMS} are the peak height and RMS of the noise in the correlation plane whose mean has been subtracted out. To simplify the calculation, we considered all points except the correlation peak as noise. The typical peak is only a few pixels wide at its base so counting these points as noise does not appreciably affect the calculation.



3a

Figure 3. a) Binarized Reference and Target Print Placed on the SLM, b) the Joint Power Spectrum Binarized Around the Mean Value, c) the Resulting Correlations.



3b

3c

In attempting to reduce the sensitivity of the BJTC we tried a new approach: we applied a kth law nonlinearity on the JPS before binarizing. Raising the JPS to powers greater than unity should accentuate the lower, more intense, spatial frequencies while suppressing higher ones yielding less sensitivity in the correlation piane. Computer simulations showed a peak in the SNR as k was varied, but it was improved by only a few percent. Further investigation of this approach is underway.

4. CONCLUSIONS

We have experimentally demonstrated a simple system that optically reads a fingerprint and optically compares it with a database for identification purposes. We have combined the previously demonstrated method of reading the fingerprint using a prism with the binary JTC technique for correlating reference and target images. The hybrid optical/digital system uses a PC to store the reference database and control the electrically addressed SLM. This system operates well using the binary SLM and we had no false alarms in our trials. Using a grayscale SLM would unlock the full potential of this system permitting one to vary the sensitivity of this system to enhance performance.

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